Sustainable Water Management in Oil and Gas Operations-A Comparative Analysis of Policies and Practices

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

Manav Rachna International Institute of Research and Studies
(Deemed to be University)

by

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Certificate

I hereby declare that the short synopsis Title "Sustainable Water Management in Oil & Gas Operations-A Comparative Analysis of Policies and Practices" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Civil Engineering under School of Engineering & Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2023-24.

It is a bona fide record of original work carried out under the supervision of Dr Anjali Gupta, Professor, Civil Engineering and Dr Dipankar Saha, Chair Professor, Centre for Advanced Water Technology and Management and has not been submitted in full or part to any other university or institute for degree or diploma.

Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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ABSTRACT

The modern world's consumption of hydrocarbon as the principal fuel is beneficial over other unconventional fuels. In the last fifteen years, thousands of wells have been drilled globally, including those drilled during shale gas boom of 2007-08. Two new technologies viz. horizontal wells and multi stage hydro-fracturing, in conventional or unconventional wells, helped in enhancing oil-gas production, triggering large requirement of freshwater, the shortage of which is looming large globally. The primary research objective encompasses exploitation strategies to accomplish environmentally responsible practices. The study seeks to examine various parameters with the goal of significantly reducing large-scale consumption of freshwater in drilling, water-injection, and hydro-fracturing. Simultaneously, it investigates the alternatives methods/processes to replace water to preserve it for future societal needs. Another crucial aspect involves analysis of effluent water treatment and disposal methodologies currently in practice. Furthermore, the research explores whether oil/gas provinces in India can be brought under different zones for mutual exploitation of effluents and freshwater. By addressing these multifaceted aspects, this research will contribute valuable insights into the ongoing discourse on sustainable hydrocarbon exploitation, providing a roadmap for policymakers, oil-gas operators and environmentalists seeking to strike a balance between energy demands and ecological responsibility.

Key Words:, *Effluent disposal, Mitigation of Freshwater usage, Oil-Gas Drilling, hydro-fracture, Recycling & Re-use*

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1. INTRODUCTION

1.1 Background

Oil and Gas are the principal energy for use as fuel. They are in use since the first century BC. In fourth century BC, petroleum was first used as a fuel in China and there was mention of use of un-refined oil in China as per an ancient Chinese text [1].

The initial idea was that petroleum was cleaner energy than coal and better than wood burning as it checks deforestation and contributes to lesser pollution of environment. Predicting an oil prospect before production, is initially made through various surveys like geological, gravity magnetic, geochemical and seismic. Once a prospect is identified and mapped, drilling is done for confirmation in the exploration stage only. This is followed by a stage of development drilling when the boundary of the reservoir is identified and the prospect delineation is completed properly.

Since the first oil well was drilled in Pennsylvania, USA in August, 1859, the oil/gas industry experienced an exponential growth [2]. There have been many booms since then, when drilling and production of Oil/Gas escalated, because of increasing oil price, demand of oil due to war, larger growth of economy, flourishing of aviation industry, new introduction of technology and many such reasons. One of the main impetuses of drilling for oil/gas on a larger scale came in 2007-08 onwards when three things happened: i) Horizontal drilling was introduced for better reservoir drainage, ii) Hydro fracturing was introduced for enhancement in oil/gas production in every tight formation specially shale. iii) United States planned to reduce dependence on imported energy (as large volume of shale gas/oil resource was discovered) and a significant increase in production was noted. The escalation of production in USA boomed a few years later, broadly inbetween 2011-2014 when oil price increased to $95 per barrel.

This exploration boom in USA impacted the states of Texas, North Dakota, New Mexico, Pennsylvania when thousands of wells were drilled for extraction of gas/oil from shale. Many countries in the world such as Poland, Germany, Albania, Russia, China, Australia, India and some countries in South America also geared up their exploration plans and started international collaboration by bringing in experts mostly from USA or sending their personnel abroad for

taking proper training and learning the trades as to how to properly plan and execute the exploration and extraction of shale gas/oil.

The huge thrust in drilling of all kinds of wells also created a demand for large volume of water. A vast majority of all these wells were horizontal and completed after carrying out hydro-fracture job in many stages which require higher volume of fresh water for drilling. Besides, operations like water injection or hydro-fracturing in vertical wells also requires huge volume of water. A minimum of 65K gallons of water are required for a conventionally drilled wells, while nearly 1.5 to 6 million gallons are required for a well where hydro-fracturing is done. Also, a conventional well under water injection requires inbetween 35000-65,000 BWPD/zone/well [3-5].

The hydrofrac job is done under high pressure, and once the production starts, large volume of water starts flowing back slowly to the wells and ultimately comes to surface. This flow back water is often contaminated with many toxic substances. Hydro-fracture job is done in several stages and the process of flowing back of these contaminated effluents keep on happening intermittently, as one flow after the other. As these jobs were done mostly in horizontal wells, so both the volume of post-drilling waste water and flow-back water is increased many folds compared to that of conventional vertical wells. In the process of pressure maintenance and EOR (Enhanced or early oil recovery) in conventional wells, a huge volume of water also comes out of the well together with gas/oil as produced water, which is also toxic. So, there are two principal challenges in the management of freshwater related to oil and gas well drilling and they are availability and requirement of fresh water and disposal of effluents [6,7].

1.2 Fresh water Requirement and availability

The fresh water consumption has been increasing because of rising population, urbanization,, rapid industrialization and because of this both surface and groundwater resources are coming under rising stress. It is becoming increasingly difficult**,** to get large volume of fresh water for the oil and gas upstream industry. Unlike North America, many of the oil fields in India, like Bombay High and Barmer oil field in the Thar desert, are located where availability of fresh water is very limited. Similar examples are also found from Gulf Countries. To overcome this problem, in this research it has been contemplated whether the different oil/gas producing

provinces of onshore India can be brought under a few zones for mutual exchanges and exploitation of freshwater and effluent water the way a similar exercise is prevalent amongst different provinces of US, supported and encouraged by the regulatory authority, central and provincial governments and followed and implemented by various operators of oil/gas fields. This has been initiated during the shale gas boom in US [8]. In this way the Indian oil/gas fields in the coastal or desert area can enjoy uninterrupted supply of freshwater or treated effluent water.

1.3 Disposal of Effluents

The effluents can be of different kinds like, post-drilling waste water, syn-production produced water and post-frac flowback water. The water coming out of such wells and related activities is toxic in nature and unfit for human and livestock consumption and even harmful for vegetation, farmlands, and bio-diversity. The challenge is to safely dispose them. The most widely accepted disposal method is to push them back in effluent disposal wells or in already abandoned wells, below a depth of 1200m which is considered to be the limit of groundwater bodies [9]. Presently, in view of scarcity of fresh water in many places and also in order to safeguard the environment and ecology, stake holders and law makers are cooperating on treatment and safe disposal of effluents, involving newer technology, stricter monitoring and developing policy framework. Depending upon the requirement, logistics and economics, the effluents may be recycled and are reused in other wells of the same oil/gas field or any other nearby fields [10].

This research aims to delve into the multifaceted dimensions of sustainable water management in oil and gas upstream operations. By critically evaluating current practices, exploring cutting-edge technologies, and assessing the regulatory framework, this study seeks to provide insights that can guide the industry toward more environmentally responsible and economically viable water management strategies.

2. LITERATURE REVIEW

2.1 General

Due to the increasing demand of oil/gas in the present-day world [11], drilling is done to explore, find and extract the oil/gas for which a huge volume of freshwater is used. Additionally, for enhanced recovery, post-drilling hydro-fracturing is done during completion of a well in a prospective zone which has become a common practice for activation of the reservoir zone. The hydro-fracturing operation requires a huge volume of water in the range of around 1.5-9.7 million gallons per well. After the hydro-fracture jobs are over, the highly toxic (sometimes radioactive too) post-frac water needs to be disposed of safely to some place beyond the reach of plant and animal kingdom. This water needs to be taken care of, by means of safe disposal [12].

This disposal of flowback water can not be made just like that arbitrarily. It has to be done honouring the existing policy and legislation with due respect for the environmental safeguarding [13].

In this research, an exhaustive review has been done on the prevailing policies and practices on how to safeguard the environment by properly managing and monitoring the (i) excess use of freshwater, (ii) replacement of freshwater use by alternate resources (iii) safe disposal of effluents and (iv) recycling.

The huge demand of water for drilling or exploration required to be reduced or required to be replaced as detailed below:

(i) During drilling considerable volume of water to the tune of thousands of gallons per well is required, so efforts through field application are thought of to save freshwater. and replace hydro-fracturing with LPG fracturing [14].

In order to save use of this large volume of water, the water-based mud drilling has been tried to be replaced by oil base mud drilling or air drilling. But it is observed that in practice, air drilling is restricted to mostly Coal Bed Methane (CBM) and shallow depth wells while replacement by Oil Based Mud (OBM) is becoming techno-economically non-viable these days because of some

curbs in the use of OBM as per the directives of regulatory authorities. Water Based Mud (WBM) has got advantage over OBM for many reasons, the a few primary ones are WBM is cost effective, less risky, environment friendly and successful in drilling for shale gas [15].

(ii) Hydro-fracturing job in a well requires huge volume of water. At least 1.5-9.7 million gallons of fresh water is easily used up per fracture job in a well. Efforts have been made to replace water with LNG which has so far not been widely accepted in the industry because of technical and economic reasons [16].

(iii) Water Injection requires at least a hundred thousand gallons of water to be injected at a time and to be maintained that way [5,12]. Depending upon the reservoir drive, it would be decided that whether the well would need any pressure maintenance and it can be done through water or gas injections. In case, water injection is must for technical reasons or due to non-availability of gas in the area, a large amount of fresh water is required for both EOR (Enhanced oil recovery) and pressure maintenance; water injection which helps in maintaining the pressure of a producing reservoir. At many places, arranging so much fresh water is difficult.

Thus, the reasons for the injection of a considerable volume of water, injected into the reservoir, are for two purposes- (a) reservoir pressure maintenance and (b) enhanced oil recovery. Water injection, besides being the main pressure maintenance tool, is also used for secondary recovery or EOR (Early or Enhanced Oil Recovery) [17].

This injected water is subsequently produced by the wells together with crude oil as produced water (PW). This water, after separation at the well head, goes to oil pit and need to be disposed off or reused safely after treatment and recycling. The aforesaid discussion points out that attempts have been made and further researches are required and also with clarity be mentioned in the policy documents or guidelines to replace freshwater suitably in drilling or fracking on a large scale or broader horizon and also in a cost effective manner.

In some fields, replacement of water injection by gas injection is done, wherever there is availability of sufficient amount of gas and technical feasibility w.r.t. oil & oil recovery exist.

This injected water is subsequently produced by the wells together with crude oil as produced water. This water, after separation at the well head, goes to oil pit and need to be disposed off or reused safely after treatment and recycling. The aforesaid discussion points out that although attempts have been made but further researches are required and clarity should be there in mentioning the instructions in the policy documents or guidelines to replace freshwater suitably in drilling or fracking on a large scale on a broader horizon but in a cost-effective manner.

Treating and reuse of waste water or flowback water or produced water significantly reduce requirement of fresh water. This also reduces substantial costs of a drilling or a hydro-fracture job of a project, as well as saving the rapidly declining freshwater resource. As the volume of water required for hydro-fracturing is very large, to the tune of 1.5 to 9.7 and even upto 16 million gallons per well [12]. Significant challenges are faced to obtain this huge volume of fresh water. Moreover, there is an environmental responsibility for effectively managing the safe disposal of flowback water and produced water.

It has been understood from different research papers derived through literature survey that the common effluents such as waste water, produced water and Flowback water are sent for treatment, recycling and reuse. The wells may either be a newly drilled effluent disposal well or an abandoned well below a depth of 1000-1200 m where the above effluents are re-injected into. The effluent water may also sometimes be discharged into surface waters after treating and removing toxins [18,19]. In US in some states there is recent legislation whereby both Federal and provincial governments do not encourage disposal of effluents in old abandoned wells or wells drilled exclusively for effluent disposal such as a Salt Water Disposal (SWD) [8].

Now a days, in a number of cases, the produced water and flow back water are recycled in order to reuse them in other wells or in the same well. However, this requires necessary storage and transportation. A large volume of fresh water can be saved this way and instead of flaring into atmosphere, gas can be utilized for pressure maintenance of the producing reservoir. This measure is also verymuch cost effective.

Most of the research papers, available on the present subject, that were studied and downloaded during literature survey have thrown light on the various methodologies of recycling of waste

water, produced water and post hydrofrac flowback water but very less in the other issue like how to replace the large volume of freshwater used during drilling and related operations[14,16,20].Therefore it can be ascertained from literature survey that the need of the hour for a proper replacement of freshwater for all drilling and related operations, is recycling of effluents followed by reuse in another well or in wells of nearby oil/gas fields for drilling, water injection and hydro-fracturing [10,21-23].

2.2 Policies and its implementation for Oil/Gas Upstream Operation

2.2.1 General

The various concerns, challenges and solutions hitherto discussed in the previous chapters on effluent disposal and freshwater use, cannot function arbitrarily as per the convenience of the operators /companies of a country, it should always be governed by the suitable laws and policies on the above subjects prevailing in a particular country. Sometimes old guidelines are reviewed and new legislation are introduced on public demand. A discussion on the policy issues are furnished below:

Legislation and Policies

In case of wells, drilled during conventional or unconventional exploration and production, there are laid down legislation and policies in many countries, but in this research synopsis, only highlights from some countries like USA, Canada, Saudi Arabia, and UAE are discussed. All these countries have got clear guidelines, regarding safe disposal of effluents w.r.t. environmental concerns, which include post drilling waste water, post fracking flowback water and produced water during production of oil. Some policies and practices w.r.t. environmental concerns in India are discussed too but the legislation and policy implementation are not very clearly defined. So, this research has got scope for defining them after comparing the policy, practice and legislation followed in these four countries and can be implemented in India.

Issues Related to Acquisition & Disposal in US

In USA, as a follow up of large requirement of freshwater for drilling, fracking and injection and disposal of effluent water due to the boom of shale gas development since last fifteen years, provinces faced a lot of problems for acquisition of huge volume of freshwater and safe disposal of effluents. Since many states are in desert area, having congested city area, arranging freshwater is difficult. Moreover due to seismicity and fragile nature of bedrock where disposal is to be made in effluent disposal wells or old abandoned wells have become no longer permitted by government to prevent contamination of toxic and radioactive effluents with groundwater by leaching or leaking through fractures and cracks developed due to seismicity. Operators and regulatory authorities together with support from both provincial and federal governments solved this by making a virtual division on either side of 98th Meridian for distributing and exchanging surplus freshwater and untreated effluents amongst 48 lower US states or provinces. Some third-party agencies are buying both the surplus freshwater and untreated effluent water, treat them and distribute them amongst provinces who need the water. falling on either sideof selecting states based upon their capabilities [8].

2.2.2 USA

The legislation which is in place in US now for shale gas exploration and extraction and development was not there before 2014, when Environmental Protection Agency (EPA) USA brought out this well framed legislation [24]. A year before i.e. in 2013, the US EPA framed a policy for CBM exploration and development also [25].

Around 2008 there was a boom for drilling of horizontal wells and hydro fracturing because of exploration, development and production of Shale Gas/oil. The waste water derived in the process used to be disposed of randomly, taking advantage of a lenient & convenient oil/gas effluent disposal policy. Complaint by common man, the environmental lobby and proactive Judiciary, forced EPA authorities to bring a policy for waste water disposal from shale gas and oil exploration as well as exploitation [26]. A separate legislation was also made for hydro-fracturing and frac derived effluents in the form of flow back water [27].

Accordingly, the USEPA, in order to frame the guidelines of effluent disposal, followed certain objectivesa) To maintain and restore physical, chemical and biological integrity of the nation's water; b) To involve stakeholders early and often during the planning process and to provide clear decision making [18].

It is important to make a note that, as per law, larger volumes of wastewater obtained from fractured shale oil and gas couldnot be discharged into surface waters due to its toxicity and contaminants.Similarly, unsystematic disposal of waste water while seeping down can pollute groundwater resources. The knowledge of the organic and inorganic impurities, in flowback and produced water (FPW) during exploration for shale gas or oil, is vital in case the effluent is reused for hydraulic fracturing. To effectively manage wastewater, a comprehensive understanding of the chemicals involved would be highly advantageous [28].

Case History from USA

Flowback water and produced water are the primary waste streams originating from oil and natural gas production site/wells. For instance, the substantial annual generation of produced water in the U.S. (ranging from 15 to 20 billion barrels) with elevated salinity levels (5,000 to 270,000 mg/L TDS) can lead to significant environmental impacts if improperly disposed of. In Pennsylvania, USA, a common disposal method involves treating produced water through wastewater treatment facilities.Analyzing the effluents released into local streams and rivers reveals TDS levels potentially three times higher than seawater (100,000 mg/L TDS), with bromide and trace element concentrations reaching up to 4,000 times higher than upstream values [29].

As per the above study, if samples are tested upto a zone of 500 m downstream from the mouth of the facility outlet where the value of the contaminated or polluted effluent water greatly exceeds values upstream of the outfall. These residues found in the stream sediments include high levels of toxic elements of NORM (Naturally Occurring Radioactive Material). Dissolved salts, metals and NORM have potential to contribute to lasting adverse ecological effects on aquatic life. This study offers a comprehensive evaluation of: (i) contaminant releases to the environment from produced wastewater of oil and natural gas producing wells; (ii) the outcome

of contamination in surface water and (iii) the apprehensions regarding the continuing ecological effects on watercourses in Western Pennsylvania of USA [18].

2.2.3 Canada

In this country, the laid down legislations are governed by certain regulations framed during 2009 which were amended on 31st December, 2009 and re-published quite recently on 17th 2023 [30].

A proper waste management system was developed in the late 1970s, in British Columbia (BC), which included introduction of an all-inclusive hazardous waste management strategy for a few Canadian provinces, specially for two large hydrocarbon producing states viz. British Columbia (BC) and Alberta (AB). After extensive research, the Canadian federal government has categorized hazardous wastes as materials capable of causing significant harm to human health or the environment if not handled or disposed of properly. The safe elimination or reduction of these hazards necessitates special techniques. It is imperative not to deposit hazardous wastes in regular landfills or discharge them into sewers. Addressing these wastes safely requires the establishment of specialized facilities. In June 1981, the recommendations of the Hazardous Waste Advisory Committee were released. These suggestions laid the foundation for the development of a state-wide hazardous waste management program. The committee endorsed the identification of a comprehensive system for managing hazardous waste in British Columbia [31].

The advisory committee recognized five most important steps for this comprehensive system:

i) expertise to store, transport, recycle, treat & disposal of hazardous wastes

ii) to identify operators for managing facilities handling hazardous waste

iii) to find out appropriate sites for these facilities

iv) to ensure proper and secure operation functioning of the system by formulating and establishing implementing relevant laws and regulations

v) agenda and plans to inform the common man and municipality about the hazardous waste management system.

The Ministry of Environment, Federal Government of Canada will continue to make further efforts in these areas in addition to the already achieved considerable advancement made in all five agenda components.

Broadly, the AER is responsible for oilfield waste, and AEP manages most other waste generated in Alberta.Despite potential differences in their regulatory processes, both agencies' requirements aim to ensure an equivalent standard of environmental protection and public safety. Regulatory responsibilities are allocated between the AER and AEP based on the type of waste management facilities or activities. The responsibilities of the oilfield waste generator are outlined, and the OGCR (Oil and Gas Conservation Rules) delineates the responsibilities for the oilfield waste receiver.

Specific Regulations and Acts

In British Columbia (BC), Canada, there are guidelines to the law for managing hazardous wastes including those generated from oil and gas upstream industries. These are provincial acts and regulations such as:

i) The EM (Environmental Management) Act.

ii) The HW (Hazardous Waste) Regulation.

iii) Reviewable Projects Regulation.

iv) Environmental Assessment Act.

Among other things, for regulating hazardous wastes in BC, the EM Act sets up a broad and wide-ranging framework [32].

2.2.4 Saudi Arabia

In Saudi Arabia, the oil-gas extraction & exploitation acts & regulations are very strict & rigid [33].

To understand and realize the environmental issueslinked to oil and gas exploration and production in Saudi Arabia, the government has implemented provisions to offer incentives for achieving environmental targets.

Articles 2 and 3 of the General Environment Law provided in the general policies and objectives focus to minimize environmental, health and economic damage arising from oil-gas upstream industry & its related operations. These include exploration, production, utilization and transportation of oil and other hazardous substances. The aim is to limit any resulting damage to the greatest extent possible and to promptly intervene in case of pollution, thereby mitigating potential long-term harm to the environment, human health, and the ecosystem (General Environmental Regulations and Rules for Implementation).

The guidelines for environmental protection (pertaining to the management of hazardous waste) are applicable to every entity engaged in the transportation, storage, treatment, and disposal of hazardous waste, as per the Executive Regulations of the General Environment Law. The general authority for interpreting and delineating the extent of these standards, as well as imposing penalties for any breaches, rests with the General Authority for Meteorology and Environmental Protection [34].

2.2.5 UAE

Abu Dhabi

In Abu Dhabi, ADCO is the company responsible for Onshore Oil Operations, conducting activities both onshore and in shallow coastal waters within the Emirate of Abu Dhabi. The national oil company is dedicated to pioneering efforts in preserving the desert ecosystem for future generations, aiming to minimize the environmental impact of its oil and gas exploration and production. A key challenge lies in effectively managing the disposal of fluid and solid effluents generated during the drilling of oil and gas wells.

ADCO to lessen the net effluent disposal, made following recommendations for minimizing the net effluent disposal [35]:

(i) Improvements in Rig Design ("zero" discharge)

(ii) Recycling of effluents and reconditioning of plants for drilling with Oil-Based Mud (OBM).

(iii) When drilling is conducted using OBM, a thermal desorption treatment facility becomes necessary for handling drill cuttings. This process ensures 100% recycling of recovered materials, transforming them into usable products.

(iv) Provision for two dedicated deep effluent disposal wells, one for mud and the other for waste water.

The collaborative efforts of Drillingteam, as guided by Health, Safety & Environment (HSE) Division, demonstrate that all hazardous wastes are being effectively handled through the proper implementation of the 3R principles (Reduce, Recycle, and Reuse). This approach aims to optimize hydrocarbon recovery while minimizing any discernible impact on the environment.

In the major oil producing fields of Abu Dhabi, the newly established waste management plants are strategically positioned at central locations, resulting in a notable reduction in transportation distances.These improvements in ADCO are aimed for lowest disposal and substantial cost saving while ensuring conformity with or possibly exceeding, the expectation of local environmental regulations.

ADNOC (Abu Dhabi National Oil Company), the national oil company of Abu Dhabi, holds the authority to establish environmental standards for theoil and gas industry in Abu Dhabi and their adherence. The ADNOC HSE department is responsible for ensuring compliance with both ADNOC's environmental standards and the UAE Federal Law Number 24 of 1999 on the Protection and Development of the Environment (the Environmental Protection Law). This compliance extends to the group of companies under ADNOC's jurisdiction, as well as those falling within the Supreme Petroleum Council (SPC)'s jurisdiction.

In accordance with ADNOC's recent implementation of a stringent policy, provisions for penalties and fines outlined in the Environmental Protection Law are enforced in cases of non-compliance with obligations, including those specified in Article 58. For violations of this article,

individuals may face imprisonment for a minimum of two years and a maximum of five years, coupled with a monetary penalty ranging from AED 200,000 to 500,000 (UAE Dirhams).

Dubai

Formed in August 2009 in the Emirate of Dubai under Law Number 19 of 2009, the Dubai Supreme Council of Energy (DSCE), in conjunction with pertinent energy entities, oversees the formulation and planning of policies related to the petroleum industry. Representatives from various government bodies, including the Department of Petroleum Affairs, Emirates National Oil Company, and Dubai Civil Aviation Authority, have been assigned responsibilities for coordinating and planning activities within the petroleum sector. Specifically, the Department of Petroleum Affairs is responsible for the administration of oil and gas extraction and production in Dubai [36].

2.2.6 India

Government of India, from time to time, has fixed some norms and regulations which included the Water (Prevention and Control of Pollution) Act, 1974; THE ENVIRONMENT PROTECTION ACT (EPA), 1986 and recent Coal Bed Methane (CBM), 1997 and Shale Gas (Oct, 2013) policies. However, the applications or implementation are not as definite and stringent like the acts & policies of the aforesaid four countries discussed above in details.

Enacted in 1974, the Water (Prevention and Control of Pollution) Act marked India's initial comprehensive effort to address water pollution concerns and establish an institutional framework. Despite being legislated to prevent and control water pollution and ensure the wholesomeness of water, the act also prohibits the discharge of pollutants into water bodies beyond specified standards and imposes penalties for non-compliance. The Act underwent an amendment in 1988 to align more closely with the provisions of the USA's Environmental Protection Act (EPA) of 1986. It led to the establishment of the Central Pollution Control Board (CPCB), responsible for setting standards for the prevention and control of water pollution. At the state level, the State Pollution Control Board operates under the guidance of the CPCB and the respective State government.However, it cannot be said for certainty whether this act has

included the provisions for prevention of pollutants to be discharged into surface water bodies from oil/gas sector also [37, 38].

The EPA, 1986 provisions clearly defined the various stipulations, specially under 3 different heads: (i) Standards for Liquid Effluent, (ii) Guidelines for Discharge of Gaseous Emission and (iii) Guidelines for Disposal of Solid Waste such as Drill Cuttings and Drilling Fluids for Offshore and Onshore Drilling Operation [39].

The Water (Prevention and Control of Pollution) Cess Act of 1997 establishes the imposition and collection of a cess on water utilization by industries and local authorities. The primary objective is to enhance the financial resources of both central and state boards dedicated to the prevention and control of water pollution [40].

Subsequent to the enactment of this legislation, the Water Cess Rules (Prevention and Control of Pollution) were crafted in 1978. These rules aim to establish standards and guidelines regarding the placement of meters, which every water consumer is obligated to install[41].

The policy on effluent disposal is honored by the major multinational oil/gas companies of India such as ONGC, OIL, Indian Oil, RIL and Cairn Energy. All these major Indian E & P companies have understood that to minimize the use of water for drilling and related operations, it is essential to effectively perform water/rainwater harvesting and recycling and reusing of the waste water, produced water and flowback water [42].

In India the policy practices and implementation are mostly by big Oil & Gas companies, so the discussion here is done company-wise:

Environmental Concerns

ONGC (Oil& Natural Gas Corporation Limited), as a pioneer of the Indian oil & gas upstream industry, continuously attempts to lessen the environmental impact associated with its activities in exploration, drilling, and production. This commitment is demonstrated through investments in cutting-edge technologies, efficient effluent and solid waste management, environmental monitoring and reporting, biodiversity conservation initiatives, and the continuous improvement

and maintenance of environmental management systems. Three Effluent Treatment Plants (ETP) have been established by ONGC & an associated pipeline was laid at Rajahmundry Oil & Gas Field in Andhra Pradesh [43].

The national oil giant has also established different strategies, targets, various objectives, systems and trainings on environment management [40]. The company has implemented thoroughly, all the regulatory measures laid down by Ministry of Environment, Forest and Climate Change (MoEFCC), State Pollution Control Boards (SPCB), Oil Industry Safety Directorate (OISD) & other statutory authorities, for saving the environment. It is crucial to understand that for providing environment protection and safety, the oil & gas industry has devoted efforts and time to address the challenges [43,44].

Waste Water Management

Another Oil Giant, the Indian Oil Corporation earlier had business in midstream and downstream industries, but in the last 10-12 years they have also come in a big way in hydrocarbon upstream industries as well. They have also recognized the major water / land pollution sources including oil spillage on land / marine environment and seepage of waste-water in land/ ground water. The different aspects of Environment Management in their plan & proposal are detailed below:

i) Indian Oil Company carefully monitored the utilization of water and quality of effluent discharged.
ii) Due to their predominant involvement in midstream and downstream operations, these companies have installed a comprehensive network of underground sewers in their refineries. These sewers facilitate the segregated collection of various wastewater streams, which undergo precise treatment in well-designed Effluent Treatment Plant (ETP) facilities incorporating physical, chemical, and biological processes. In marketing and pipeline locations, effluent water is directed through oil-water separators. The company has implemented advanced treatment systems such as Ultra Filtration and Reverse Osmosis to treat effluents, converting them into demineralized water or for use in cooling towers as makeup water. These initiatives have resulted in the significant reuse of 80-95% of wastewater in refineries, leading to a substantial reduction in fresh water consumption [45].

Freshwater Management

India provides a few notable instances of effective Freshwater Management. Cairn Energy, the largest private oil and gas exploration and production company in India, operates in states like Rajasthan, Gujarat, and Andhra Pradesh, with the first two falling under the arid regions of the country. Given that many of their operations are situated in areas with limited access to potable water, efficient water sourcing and utilization become imperative for the continuous functioning of their activities. Cairn has set specific targets, including (i) achieving over 80% water reuse and recycling by 2025,

(ii) increasing produced water recycling to over 97% by 2025, and (iii) developing 300+ structures by 2025 in the Barmer district to facilitate the harvesting of 3.0 MMKL of rainwater annually [46].

Overall Water Management

Oil India Ltd. (OIL) has been championing the awareness of water management for quite some time now as they have understood over the years how essential this natural resource is, not only for oil & gas operations but also for society and ecosystems. However, the availability of good quality water for all has been restricted because of reduction in freshwater supplies due to increasing usage followed by rising demand for fresh water sources. In this context, to mitigate the risks of physical, reputational and regulatory challenges, in terms of access to water, OIL has adopted a pro-active and prudent approach. The company has installed systems in strategic places to measure, monitor and manage water consumption. The National Oil Company has been identifying opportunities for water conservation and ensuring that their withdrawal does not significantly impact water sources. In the last few years, there has been no reporting of any significant oil spills or any significant effect on water bodies because of discharge from any of the operations [47].

OIL is keen to minimize its water consumption and some of the key initiatives implemented in recent years are given below:

i) Water Harvesting: OIL has implemented an experimental Rainwater Harvesting System to assess the efficacy of the system on the rooftop of its Office Complex. The collected rainwater undergoes a filtration process and is subsequently stored in a dedicated tank for activities such as gardening and cleaning. This system conserves approximately 1,500 litres per day and an estimated 438,000 litres annually, assuming an 80% utilization rate[48].

ii) Recycling of water- OIL has a WTP(Water Treatment Plan) in its operational area of Duliajan. which has got a capacity of operating 4 MGD (Million Gallons per Day) of water. The produced water after treatment in the WTP, is used for domestic and industrial purposes in OIL Township and nearby installations. Water conserved through this process is approximately 900KL per day and the same is expected to be about 2,65,650KL per annum with 90% efficiency of the process.

2.3 Research Gaps

Most of the research work on sustainable water management for oil and gas exploration and production are focused mostly on five domains a) environmental safety, b) safe disposal of effluents in effluent disposal wells, c**)** reinjection of effluents in an abandoned well d) recyclingof post drilling wastewater, produced water and post frac flowback water after thorough chemical treatment for toxin removals, e) reusing this recycled water in the wells as a replacement of freshwater for drilling and other stimulation jobs.

Majority of the research papers have contributed significantly in the direction of the various methodologies of recycling and reusing post drilling waste water and post hydrofrac flowback water but very less number of literatures threw any meaningful light towards replacing freshwater in drilling, hydro fracturing, water injection and other related activities.

Contemporary researches point out to the facts that substitution of water as a drilling fluid or slick-water for hydro-fracture(HF) is not forthcoming. Also, changeover of water injection by gas injection for pressure maintenance and secondary recovery is not very widespread and popular. So, what is popular, is to find some replacement through the recycling of the effluents or waste water, flowback water and produced water and reuse them in other wells in and around the oil/gas field as an alternative of fresh water.

However, getting exact replacement of freshwater is not possible but advance researches have further suggested that by recycling the effluent water, similar type of fluid as freshwater, with low TDS and softened to the maximum extent, may be obtained, and can then be reused in wells in thenearby fields. So, if techno-economically viable the process of recycling followed by reusing is the best option for a proper replacement of freshwater and in this manner use of the latter can be substantially minimized and saving the source aquifers of freshwater for future use of mankind.

So, here lies the research gaps in both contemporary and existing researches on the topics on substitution of fresh water for preparation of mud for drilling, in preparing slick-water for hydro-fracture and in injecting water through injection wells into a producing reservoir for secondary recovery and pressure maintenance. Some recent research has also suggested that by mutually exchanging freshwater and effluent water amongst various oil producing provinces in a country, both the needs of safeguarding freshwater for future useful societal needs and effective management of effluent disposal are properly utilized.

3. DESCRIPTION OF BROAD AREA AND PROBLEM STATEMENT

3.1 Broad Area of Description-General

Though it is being practiced in some cases, however, not many researches are available on replacement of fresh water by brine or saline water or any other chemicals in drilling, hydro-fracture and water injection. From the available literature, and common field applications, it is understood that, gas injection to some extent is replacing water injection in some compatible oil fields and sometimes air drilling is also being done [49]. Hydro-fracture is being experimented by replacing water with liquid petroleum gas (LPG) [50]. However, all these replacement methods are not widely successful, because of a dearth of quality research that could establish commercial viability.

It is therefore required to put a thruston similar ongoing research or technical work of such efforts made for freshwater replacement. If such reports or papers are not available then there is a genuine research gap which needs to be addressed to in near future. This will give rise to many such fields of researches/research topics. Besides there is also a challenge to build up a well drafted policy guidelines for India taking a cue out of the best practices from the other countries.

This research will represent a review on how the collateral impacts are created on water resources, both volumetric and quality wise, as the petroleum exploration is done and the production continues. A thorough research is underway based on the published papers, book chapters, reports from various Government Departments and organization involved in this field. Various field situation experienced by the researcher during his 42 years of experience in oil & gas sector is also used to synthesize the issues. The authors have also carried out extensive interaction with the industry persons during the course of the preparation of manuscript.

3.2 Water Management Issues

The broad contours of water management issues are proposed as:

A) Huge requirement of water for exploration for oil/gas, drilling for finding hydrocarbon, fracking for enhancement of production and injection for secondary or enhanced recovery and for reservoir pressure maintenance.

B) Safe disposal/reuse of large volume of effluents derived as waste water, flowback water and produced water.

C) How to find a replacement of fresh water for drilling, fracking & injection so that the resource can meet up other pressing societal needs.

D) To check the possibility of dividing India into about three or four onshore oil/gas producing provinces such as (i) Assam and Assam-Arakan in North East India; (ii) East Coast Belt in Bengal, Andhra and Tamil Nadu and (iii) Western arid-semi arid region. They are described below in short:

Zone (i): Tertiary Deposits of North Eastern States including oil/gas producing Assam Basin and gas producing Assam –Arakan Basin of Tripura. Surface and groundwater resources are plenty. Abundance of Rainfall. No volumetric issue, only quality may be of a little concern. Seismically quite active;

Zone-(ii): Tertiary Deposits in Bengal Basin in West Bengal, K-G Onshore Basin in Andhra Pradesh and Kaveri onshore Basin in Tamil Nadu. Oil and Gas are in almost equal abundance. Fragile hydrogeology because of trans boundary, off shore onshore aquifers. Both volumetric and quality issue;

Zone (iii): Tertiary Deposits of Cambay Basin in Gujarat, Barmer-Sanchor Basin in Rajasthan. Oil and Gas in almost equal abundance. Fragile hydrogeology because of limited resource and transboundary, off shore onshore aquifers. Both volumetric and quality issue. Seismically sensitive.

3.3 Problem Statement

Although there has been a thorough Literature Survey, still it has been seen that, not many researches are available on replacement of fresh water by brine or saline water or any other chemicals in drilling, hydro-fracture and water injection. From the available literature, it is understood that, gas injection to some extent is replacing water injection in some compatible oil fields and sometimes air drilling is also being done[46].

Hydro-fracture is being experimented by replacing water with liquid petroleum gas (LPG) [47]. However, all these replacement operations are not widely successful, because of a dearth of quality research that could establish commercial viability. It is therefore required to put a thrust on similar ongoing researches or technical works of such efforts made for freshwater replacement.

If such reports or papers are not available then there is a genuine research gap which needs to be addressed to in near future. This will give rise to many such fields of researches/research topics. Besides there is also a challenge to build up a well drafted policy guidelines for India taking a cue out of the best practices from the other countries.

4. RESEARCH OBJECTIVES

After going through intensive research, following research objectives have been identified:

1. To reduce the use of large volume of fresh water and to understand the possibility of alternative methods/processes for replacing fresh water in drilling, water injection and hydro-fracturing (fracking), various relevant and related parameters have been studied thoroughly.

2. To analyze effluent water/fluids treatment and disposal methodologies in practice, taking into account the environmental concerns including measures to prevent violations.

3. To identify the effectiveness of recycling of effluent water/fluids and reusing them for drilling, fracturing and injection operations.

4. To compare policies and practices prevalent in oil rich countries like USA, Canada, Saudi Arabia and UAE to identify the gaps concerning various oil reservoir typologies in India followed by implementation of the beneficial and environment friendly aspects of the policies for operators in India.

5. To propose a set of rules or criteria as guidelines for effective management of freshwater use and effluent disposal to mitigate adverse impacts of water and environment.

5. RESEARCH METHODOLOGY

Our proposed research work will be carried out by the following methodology.

1 Conducting Literature Review

A comprehensive review of existing literature related to water usage in drilling, water injection, and fracking will be conducted. Alternative methods and processes globally employed to replace fresh water in these operations will be explored, with a focus on understanding associated challenges and benefits.

2 Analyzing Effluent Water/Fluids Treatment

Current methodologies for treating and disposing of effluent water/fluids in the oil and gas industry will be investigated. Environmental concerns linked to existing practices will be analyzed, and measures to prevent violations and ensure compliance with environmental regulations will be examined.

3 Assessing Recycling Effectiveness and Innovation

The effectiveness of existing recycling practices for effluent water/fluids will be evaluated. Innovative methodologies for recycling will be explored, and feasibility tests, experiments, or simulations will be conducted to assess their viability.

4 Comparative Analysis of International Policies

Policies and practices related to water usage and effluent disposal in oil-rich countries such as the USA, Canada, Saudi Arabia, and UAE will be compared. Gaps and differences in policies impacting oil reservoir typologies will be identified, and beneficial aspects of these policies will be highlighted for potential implementation in India.

5 Proposal of Guidelines

Based on the findings, a set of rules or criteria will be proposed as guidelines for the effective management of freshwater use and effluent disposal. Guidelines will be tailored to consider the unique characteristics of oil reservoirs in India, and recommendations for implementation and enforcement mechanisms will be provided.

6. EXPECTED OUTCOME OF THE RESEARCH

Based upon detailed discussion derived from review papers and related publications, existing guidelines, policies, and practices, as mentioned above and taking relevant cue from the undersigned's 42 years of experience in the oil/gas industry following expected outcome of the research could be:

1. Exploration of the possibility of creating zones for mutual freshwater exchanges among different oil/gas-producing provinces in India.
2. Potential of mutual freshwater and effluent water exchanges among various oil-producing provinces in a country. This exchange could effectively balance the needs of safeguarding freshwater for future societal needs while ensuring the proper management of effluent disposal.
3. Identification of gaps in policies relevant to various oil reservoir typologies in India, providing a foundation for adapting and implementing beneficial and environmentally friendly aspects of foreign policies.
4. Proposing a framework to mitigate adverse impacts on water resources and the environment, offering practical guidelines for operators in India to adopt sustainable practices in their oil and gas activities.
5. Clearwater, associated with sanitation, is the 6th SDG Goal, highlighting the importance of proper wastewater management and effective disposal or reuse. Clean Energy is the 7th SDG goal. Achieving these goals contributes to ensuring a contamination-free environment and provides ample water for various purposes, including sanitation, irrigation, plantation, vegetation, livestock, and potentially human consumption with high-standard treatment during recycling.

These 7th &8th SDG Goals will together promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (8th SDG Goal) and will build resilient infrastructure, promote sustainable industrialization and foster innovation(9th SDG Goal).

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